

Search for CFC alternatives
begins in earnest
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FEBRUARY 8, 1988

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CHEMICAL & ENGINEERING

NEWS

Great Lakes Pollution

Less than before, but
stubborn problems remain

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News of the Week

■ China announces that National Chemicals Import & Export Corp. will go multinational and that it plans to open Chinese borders to broader foreign trade and investment. **Page 4**

■ Shell Oil Co. and the Army have agreed to share costs of cleanup of federal arsenal property in Colorado where more than 140 specific hazardous waste sites are thought to be. **Page 5**

■ Although chemical warfare disarmament talks have resumed in Geneva, prospects for a treaty are dim in face of the many contentious issues still to be resolved. **Page 5**

■ Du Pont begins production of test lots of fluorocarbon-134a, a potential substitute for ozone-depleting chlorofluorocarbons. **Page 6**

■ New fat-dissolving enzyme for detergents will be produced by Novo Industri, a Danish bioproducts company, at manufacturing facility in Hokkaido, Japan. **Page 6**

Cover: Spider Island in Lake Michigan. Photo by Timothy J. Kubiak, U.S. Fish & Wildlife Service

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Business

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American Cyanamid is manufacturing isocyanates in its new world-scale production facility in Willow Island, W.Va. **Page 11**

European chemical industry could see slowdown in growth this year compared with 1987. **Page 12**

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Chlorofluorocarbon producers scramble to develop alternatives to CFCs to meet deadlines Montreal protocol would impose. **Page 17**



Special Report

Although much progress has been made since the Great Lakes cleanup effort was initiated in 1972, the effects that persistent contaminants may have on aquatic life, fish-eating birds, and humans are cause for concern. **Page 22**

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LETTERS

Importance of safety

SIR: Recently, while shopping for a chemistry set for my niece's Christmas present, I had the opportunity to examine several sets produced by two companies: Educational Design Inc. and Natural Science Industries. I was appalled to find cover illustrations/photographs on the packages of these sets featuring bright-eyed and excited males (no females) with no eye safety on. Although one of the sets at least showed a picture of its contents, which included safety glasses, it still showed the young man closely examining an experiment without eye protection. It is disturbing to see such images displayed that could clearly mislead the consumers of these sets as to the importance of safety considerations when using this equipment.

I am writing independently to the manufacturers to complain and urge them to remedy this situation. I would urge ACS membership, and indeed the leadership, to apply the appropriate pressure to change these companies' marketing and displays. I believe this is a large market where safety is of paramount concern.

Joseph A. Gardella Jr.

Associate Professor of Chemistry
Associate Director, Surface Science Center
State University of New York, Buffalo

Learning to love metric

SIR: Hugh W. Thompson (C&EN, Jan. 4, page 4) makes an assumption that is totally unsupported by the data. He believes that the use of accepted metric terms confuses the public and somehow affects the ability of scientists to communicate with the nonscientific community. He underestimates the public's ability to handle terms such as hertz and Celsius [the other names he mentions, torr and dalton, are not accepted nomenclature in the International System of Units (SI) as set forth in ASTM Publication E 380-86, "Standard for Metric Practice"].

The public certainly has had no difficulty comprehending terms such as volt, faraday, watt, or Fahrenheit, so why the fuss about other terms of measurement that take their names from those scientists who contributed to that field of science?

The SI Metric System of Measurement is a rational, coherent system, based on the well-known metric (decimal) system, and is in exclusive use in almost all countries in the world, with the notable

exception of the U.S. In an international market, where more and more metrically designed and manufactured goods are being imported into and exported out of the U.S., it is only a matter of time before SI metric becomes the accepted system of measurement here. And at that time, the scientific and nonscientific public will have little difficulty in learning the new terms and names, especially since they have been exposed to metric goods for many years (camera film, skis, automobiles, soft-drink bottles, etc.).

The fact that the names of many of the measurement units happen to honor scientists of the past will then surely heighten the public's enthusiasm, understanding, and willingness to accept this novel, easy-to-use and easy-to-understand system.

Jack G. Lowenstein

Director of Administration and
Metric Coordinator, Chemical Groups
FMC Corp., Princeton, N.J.

Individual research grants

SIR: With due respect to our colleagues in the arts, the undeniably most significant contribution of the U.S. to the human civilization has been in the area of science. It resulted from the work of many scientists who have found the optimal conditions for the expression of their creativity in this country. In turn, it has been one of the dominating factors behind its present economical and political strength.

It is not necessary to go far back in history to see that the decline of any society has been always preceded by the decline of its cultural values. This point seems to be well understood in many countries of Western Europe and in Japan in particular. The broad support for individual research in those countries is becoming the envy of many U.S. scientists. Even a casual conversation with U.S. colleagues leaves no doubt that it is now more difficult than ever to obtain individual research support from federal sources.

I would like to voice my concern about the apparent imbalance between

Correction

• Jan. 11, page 5: The investment banking firm that assisted Hoffmann-La Roche in its bid for Sterling Drug is Morgan Guaranty, not Morgan Stanley.

CHINA'S REFORMS:

Chemical firm to go multinational

As part of its far-reaching economic and political restructuring—aimed at quadrupling industrial and agricultural output between 1980 and 2000—China has just announced two major steps opening the country to wider foreign trade and investment.

In the first development, China's National Chemicals Import & Export Corp. (Sinochem) will go multinational and diversify. In the second, Communist party leader Zhao Ziyang has announced an export-oriented economic plan calling for greater links with foreign investors and world markets and for mobilization of science and technology to boost production.

Sinochem was founded in 1950 as an import-export business for chemicals and petroleum. It is China's largest trading company, doing \$8.3 billion in business in 1987, up \$1.6 billion from 1986.

However, under China's "open door" policy more and more Chinese companies are importing and exporting. Rather than just compete with them, says general manager Zheng Dunxun, Sinochem will "explore new channels for the country to gain foreign currency. We will make efforts to promote economic efficiency and develop diverse operations, and eventually turn Sinochem into a new kind of socialist transnational corporation."

The firm will become a comprehensive economic entity, handling not only imports and exports but production, finance, transport, insurance, leasing, advertising, real estate, and services. In the future it will turn over only part of its annual profit to the state, keeping the rest for further development.

It also will diversify into other oil- and chemical-related businesses. With more autonomy, it can seek foreign funds, launch joint ventures

U.S. chemical exports to China are triple imports

\$ Millions ^a	Exports ^b	Imports ^c
ALL CHEMICALS	\$593	\$180
Fertilizers ^d	197	0.03
Plastics, resins	163	4
Organic chemicals	117	36
Inorganic chemicals	63	38
Pharmaceuticals ^e	24	28
Essential oils, perfumes	3	14
Dyes ^f	2	6
Explosives, pyrotechnics	0.1	41
Others	24	14
ALL COMMODITIES	\$2743	\$5891

^a For 10 months in 1987. ^b Free alongside ship values. ^c Includes cost, insurance, and freight. ^d Manufactured. ^e Includes medicinals. ^f Includes tanning, coloring products. Source: Department of Commerce

and coproduction agreements, and develop barter trade and other forms of countertrade. In addition, it can process materials provided by customers, act as agent for others, and import and export chemical technology and equipment.

The company already has initiated such activities. It has moved into oil refining, set up a petroleum station in Singapore, and has plans to build filling stations in Europe. It has a shipping joint venture, and it recently expanded barter and entrepôt trade in petroleum, chemical fertilizers, and plastics. It already has 40 branches in China and 23 overseas subsidiaries, offices, and agencies.

Meanwhile, Zhao has set out an economic reform strategy emphasizing accelerated export development in China's coastal provinces and calling for more foreign investments, technology, management expertise, and technical talent to advance production. Chinese leaders have been greatly impressed by the rapid, export-led development of what they call the "four drag-

ons" of Asia—South Korea, Taiwan, Hong Kong, and Singapore.

Industries in coastal areas would import raw and semifinished materials from abroad, process them to increase their value, and then re-export them, Zhao says. Attraction of foreign investment is a top priority: "When foreign businessmen have shared interests with us, they will pay attention to product quality, technological improvement, management, and marketing; and this is in our interest."

Improved management is another top priority. "For a very long time," Zhao notes, "the working discipline in many of our plants has been lax, and financial and material management chaotic. In short, outdated management has been a very common phenomenon in our enterprises and the waste caused in this regard is shocking." In the trade area, "Foreign trade enterprises should have full authority over management and full responsibility for profits and losses."

One way of speeding up management reform, Zhao adds, is to permit foreign businessmen directly to administer Sino-foreign joint ventures as well as enterprises they wholly own in China "in accordance with international norms. We should create an environment in which foreign entrepreneurs can do business just as they would in most other countries in the world. The main criterion for judging whether an investment climate is good is to see whether it can produce profits." And he terms "mistaken" the previous Chinese belief that "letting foreign businessmen administer enterprises meant losing our sovereignty."

Zhao notes that China has a stronger scientific and technical work force than do most developing countries, but so far institution-

al and policy factors have limited its contribution to China's development efforts. Therefore, he urges mobilization of scientists and technicians to participate in international exchanges and competition. He advocates "hooking up research units' benefits with their research results." Thus, "The better their results and the more these results are needed by society, the greater the research units will be rewarded." He doesn't worry that this will encourage only short-term research: China currently has "far too few" projects that can produce short-term results.

Moreover, the Chinese leader would encourage scientists to become entrepreneurs: "We should let scientific and technical personnel operate enterprises directly—especially the technology-intensive industries." And he advocates setting up knowledge-intensive enterprises close to research centers or schools.

China is already doing well at increasing its exports to the U.S. Clayton K. Yeutter, the U.S. trade representative, was in Beijing last week to sign a pact cutting China to just 3% annual growth in textile sales to the U.S. for the next four years, and to discuss reduction of Chinese trade barriers. Through October last year, the U.S. imported \$5.9 billion in Chinese goods and exported just \$2.7 billion. Chemicals are a bright spot, however, with U.S. exports more than triple imports.

Richard Seltzer, Washington

Shell, Army to clean up Colorado arsenal site

Under a federal consent decree, the Army and Shell Oil Co. have agreed to share the costs of cleaning up toxic chemical wastes at the Rocky Mountain Arsenal in Colorado. The cost of the operation at the 27-square-mile site could be more than \$1 billion, making this the most expensive cleanup ever negotiated.

The Army manufactured chemical and incendiary weapons during World War II at the arsenal and made nerve gas there during the Korean War. Shell Oil came onto the site in 1952 when it bought an existing company that was producing

pesticides there. Shell continued the operation until 1982. More than 140 hazardous waste sites are thought to be on the arsenal property.

The agreement settles a 1983 lawsuit against Shell by the Justice Department asking reimbursement for government costs already incurred at the site. "The consent decree is the result of two years of intensive negotiations," says acting assistant attorney general Roger J. Marzulla. "It is important to stress the cooperative efforts by the Army, Shell, and other federal agencies that led to this proposal."

Although the decree sets out no specific cleanup schedule, the current goal for completion of work is the year 2000. R. G. Dillard, Shell's vice president for public affairs, says that the decree does not specify any particular cleanup plan. "Future studies will determine the scope of the remedial plan," he says, "but the decree does provide for some

very significant work to commence before the final plan is selected."

The total cost of this enormous cleanup will be shared by Shell and the Army under a formula contained in the decree. For the first \$500 million, each will pay half the expense. For costs between \$500 million and \$700 million, Shell will contribute 35%, and for expenses in excess of \$700 million, Shell will pay 20%.

The formula is based on several factors, including the relative quantities of contaminants disposed of or released by each party and the degree of toxicity of those wastes. In addition, the consent decree specifies 13 remedial cleanup projects that the Army and Shell are supposed to complete before development of final cleanup plans. The cleanup plan for the arsenal's soils and water is to be completed by 1992, and plans for cleaning up groundwater off the site a year later.

David Hanson, Washington

Progress on chemical warfare treaty slows

Chemical warfare disarmament talks have resumed in Geneva at the Conference on Disarmament. The optimistic glow of last year's progress toward totally eliminating chemical weapons is fading in the face of many contentious issues remaining to be resolved.

The pace of the talks quickened last year because the Soviet Union made several spectacular concessions. "Major east-west or U.S.-U.S.S.R. differences, particularly on verification, were resolved," says Elisa D. Harris, visiting fellow at the Royal United Services Institute in London. But this year's session will focus on more politically difficult north-south issues. Among these are "who will pay for implementing the convention, and whether technical assistance will be given to developing countries as a quid pro quo for their participation in it," she adds.

Some supranational organization will have to be established to ensure compliance with a chemical warfare treaty. But its size, organizational structure, and operational costs need to be resolved.

Nonaligned nations with no chemical weapons are reluctant to be-

come parties to a treaty that would require a costly organization. They would, however, as enticement to enter into the accord, welcome economic assistance to develop their own chemical industries. The U.S.



Ban would eliminate need for training in protective gear such as this

Search Intensifies for Alternatives To Ozone-Depleting Halocarbons

Anticipating ratification of Montreal protocol, producers of chlorofluorocarbons are striving to develop substitutes for fully halogenated CFCs

Pamela S. Zurer, C&EN Washington

"What grand opportunities there are for the businesses that come up with solutions first," Environmental Protection Agency economist Stephen Anderson recently told an international conference on substitutes and alternatives to ozone-depleting halocarbons. "It's a billion-dollar opportunity," he said. "Best of luck in earning large profits while protecting stratospheric ozone."

Anderson's exuberant attitude was decidedly more upbeat than that of most of his audience—more than 500 scientists, engineers, and business executives from industries that produce and use chlorofluorocarbons (CFCs) and halons (fluorocarbons that contain bromine atoms). They gathered in Washington, D.C., last month to exchange information and ideas among themselves and with researchers and regulators from government. Although few are as spirited as Anderson, they are turning to meet the formidable challenges that lie ahead with determination.

The force behind those challenges and the impetus for the conference—sponsored by EPA, Environment Canada, and the Conservation Foundation—is the Montreal Protocol on Substances That Deplete the Ozone Layer. That international agreement will freeze consumption of CFCs at 1986 levels on July 1, 1989. Later cuts in output will reduce CFC consumption first by

20% by mid-1993, then by an additional 30% by mid-1998. Consumption of halons is to be frozen at 1986 levels.

Although signed by the U.S., the European Community, and 23 other nations last September, the Montreal protocol will go into effect on Jan. 1, 1989, only if it has been ratified by at least 11 countries accounting for two thirds of world consumption. None have yet done so, but chances are excellent that the agreement will be quickly ratified. In the meantime, neither the U.S. government nor industry is standing still waiting for the other shoe to drop.

EPA has already proposed regulations, expected to go into effect

Aug. 1, that will control halocarbon output in the U.S. through a system of production quotas. Companies that made CFCs and halons in 1986 will be allocated "rights" to produce the chemicals based on the firm's share of total 1986 output. Market forces will control which users get the reduced supplies available—and at what price.

Producers of CFCs are scrambling to develop alternatives to fully halogenated halocarbons, particularly CFC-11 (CFCl_3) and CFC-12 (CF_2Cl_2). These two compounds, the largest-volume CFCs, are heavily used in refrigeration and air-conditioning, and as blowing agents for producing polymer foams.

"The search for CFC alternatives



"This isn't going to do the old ozone layer any good, that's for sure."

Drawing by Ross. © 1987, The New Yorker Magazine Inc.

began in the mid-70s," notes Joseph M. Steed, environmental manager for Du Pont's Freon products division. Spurred by EPA's ban on the use of CFCs in most aerosol products, the major producing firms began to look at the chemical and physical properties and toxicity of likely alternatives.

After a certain point, however, the companies declined to invest the resources necessary to proceed to plant development and long-term toxicity tests. "The customer demand wasn't there 10 years ago," says S. Robert Orfeo, senior research associate with Allied-Signal.

But now the Montreal protocol is providing the incentive for CFC producers to move quickly into alternatives. "It will be difficult to provide the needed materials in time," Steed says, citing an estimated five to seven years before toxicity testing and design and construction of new plants can be completed.

The chemical candidates receiving the most attention as likely substitutes are fluorocarbons-123 (CHCl_2CF_3), -134a (CH_2FCF_3), and -141b ($\text{CH}_3\text{CCl}_2\text{F}$). The physical properties of these compounds are similar enough to CFC-11 and CFC-12 so that they could be substituted in certain uses without major redesign or refitting of existing equipment. None showed any major problems in acute toxicity tests. All three carry hydrogen atoms that make them susceptible to degradation in

the lower regions of the atmosphere—unlike the fully halogenated CFCs whose long half-lives let them survive until they reach the stratospheric ozone layer.

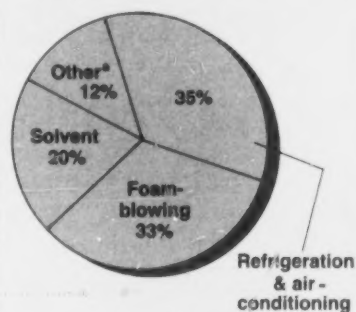
Two of these possible substitutes, 123 and 134a, will undergo long-term inhalation toxicity tests in a multimillion-dollar cooperative program set up by 13 CFC producers from the U.S., Europe, and Japan (C&EN, Jan. 11, page 6). This unprecedented collaboration is aimed at avoiding duplication of effort and shortening the time required to complete the tests.

The failure to include 141b in the toxicity testing program raised some eyebrows at last month's conference. Pennwalt Corp. is pushing 141b as "the blowing agent of the future." The firm predicts 141b will cost less than 123, the other viable candidate for a foam-blowing substitute. Interestingly, Pennwalt is not among the U.S. CFC producers that joined the cooperative testing program.

"We figure we can handle two compounds in the time-frame established by the protocol," says Michael R. Harris, halocarbon development manager for ICI Americas, in explaining why 141b has not been included in the consortium's plans. "It's simply a matter of prioritization—we hope we've judged correctly."

Although there are only a limited number of chemical companies that produce CFCs and halons, EPA

Cooling, foam-blowing are largest U.S. CFC uses



1985 total consumption = 610 million lb

* Includes aerosols, sterilization, food freezing, and other miscellaneous uses.

Source: Environmental Protection Agency

estimates there are 10,000 firms in the U.S. alone that use the compounds. The impact of the new restrictions will vary widely among user industries. Most will need to apply several different strategies—conservation, recycling, the use of substitutes, redesign, and retooling—in order to cope.

The electronics industry, both in the U.S. and abroad, faces one of the toughest problems in adjusting to curtailed CFC production. The use of CFC-113 ($\text{CCl}_2\text{FCClF}_2$) as a solvent for cleaning electronic assemblies has been growing in the past few years at a double-digit rate.

"One of the biggest stumbling blocks in the negotiations for the Montreal protocol was how to handle CFC-113," says Eileen Claussen, director of program development in EPA's office of air and radiation. "Its use is projected to keep rising and it is the most difficult CFC to replace."

The low toxicity, nonflammability, and stability of CFC-113 make it a "wonder product for high technology," says Morris A. (Bud) Ward, director of environmental and occupational health for the American Electronics Association. "Over the past decade it's become the solvent of choice: The industry had been eager to get away from the environmental and toxicity problems associated with methylene chloride and trichloroethylene. We've been concerned that not much has been

Eight halocarbons to be controlled under Montreal protocol

Substance	Ozone-depleting potential ^a	Atmospheric lifetime, years	Major uses
GROUP 1—Production cuts mandated			
CFCl_3 (CFC-11)	1.0	75	Flexible foam, rigid polyurethane foam, refrigeration, air-conditioning
CF_2Cl_2 (CFC-12)	1.0	111	Rigid polyurethane and rigid nonpolyurethane foam, refrigeration, air-conditioning, aerosols, sterilization, food-freezing
$\text{C}_2\text{F}_3\text{Cl}_3$ (CFC-113)	0.8	90	Solvent
$\text{C}_2\text{F}_4\text{Cl}_2$ (CFC-114)	1.0	185	Rigid nonurethane foam, refrigeration, air-conditioning
$\text{C}_2\text{F}_5\text{Cl}$ (CFC-115)	0.6	380	Refrigeration, air-conditioning
GROUP 2—Production freeze mandated			
CF_3BrCl (Halon-1211)	3.0	25	Portable fire extinguishers
CF_3Br (Halon-1301)	10.0	110	Total flooding fire-extinguishing systems
$\text{C}_2\text{F}_4\text{Br}_2$ (Halon-2402)	b	na	Fire extinguishers

^a Estimates depending on chlorine and bromine content and atmospheric lifetime. Potentials are set relative to CFC-11, which is assigned a value of 1.0. b To be determined. na = not available. Source: Environmental Protection Agency

happening in terms of substitutes for 113."

Claussen and Ward, like many others at the conference, were extremely interested to hear that AT&T and Petroferm Inc., of Fernandina Beach, Fla., have developed a substitute for CFC-113 in certain electronics manufacturing processes. Indeed, a press conference to announce the development was jammed with more representatives of the electronics industry, regulatory agencies, and environmental groups than reporters.

The substitute cleaning agent is a biodegradable mixture of terpene hydrocarbons and surfactants known as Bioact EC-7, according to Petroferm's chief executive officer William R. Galloway Jr. "Extensive experience with AT&T and some experience with other manufacturers has clearly demonstrated that it cleans printed circuit boards as well [as], or better than, chlorofluorocarbons or chlorinated solvents," he says.

David R. Chittick, AT&T engineering vice president, says the Petroferm formulation cleans soldering flux residues from electronic components, even from advanced surface-mount circuit boards, which are much more difficult to clean than older designs. AT&T, which used about 3 million lb of CFC-113 in 1986, expects to replace about one quarter of that usage with Bioact EC-7 during the next two years.

AT&T has tested the terpene sol-



Harris: a matter of setting priorities

vent in three of its plants, using a new cleaning system designed by its scientists at Bell Labs. The firm says it will make its technology available to other manufacturers who wish to use it. Even counting the cost of replacing the cleaning machinery, Bioact EC-7 costs about the same as CFC-113, Chittick says, and may become cheaper as CFC costs rise under the restrictions of the Montreal protocol.

"The AT&T and Petroferm announcement is very encouraging news but it sounds too good to be true," Ward says. "We'll have to look at it with healthy skepticism. It's one piece of the puzzle in reducing CFC-113 use."

Another industry that will be hard hit by restrictions on CFC consumption is rigid insulating foam manufacturing. CFC-11 is used to blow polyisocyanurate and polyurethane foam insulation that is widely used in new construction and remodeling.

The CFCs used in mechanically producing such foams are entrained within the insulation and contribute to its desirable properties as barriers against thermal loss. In the long run, foam insulation manufacturers are looking to alternative fluorocarbons such as 123 and 141b to replace CFC-11. Until those materials are on the market, however, the industry is very vulnerable to competition from other types of insulation such as glass fiber.

"The hard facts are that a produc-

tion freeze at 1986 levels is actually a reduction from the levels we are using today because we've been growing at 20% a year," says Lorraine M. Aulisio, vice president for technical services and regulatory affairs for Celotex Corp. That firm is the largest producer of rigid insulating polyisocyanurate.

The industry already has reduced its emissions from manufacturing from 10% to 5% of the CFCs used, Aulisio says, and can't expect to conserve much more in that area. She says the industry is looking at the use of extenders or blends in foam-blowing.

"We must face the reality of change," Aulisio says. "We're working hard to ensure our short-term survival."

Other industries that use CFCs—such as manufacturers of other types of foams, refrigeration, and air-conditioning equipment—although facing major adjustments, are not in such desperate straits. Home air-conditioning, for example, has already switched almost entirely to CFC-22 (CHClF_2) from CFC-12. In refrigeration and automobile and commercial air-conditioning, large reductions in emissions could be made simply by recovering and recycling during servicing. Over the longer term, new equipment can be designed to use the expected substitutes such as 134a.

Because halons contain bromine, which reacts faster with ozone than chlorine, atmospheric chemists think those compounds are a bigger threat to stratospheric ozone than CFCs on a molecule-per-molecule basis. However, halons are subject only to a freeze, not a production cut, under the Montreal protocol. But their use has been growing so fast a freeze alone will have a major impact on producers and users.

The low toxicity and noncorrosivity of the halons have made them the agents of choice for protecting expensive or highly sensitive equipment from fires. Halon 1301 (CBrF_3) is used in systems that flood entire rooms containing computer installations with the chemical when a smoke detector is triggered. Personnel need not be evacuated and the halocarbon extinguishes the fire without damaging sensitive electron-



AT&T's Chittick points to circuit board that Bioact EC-7 will clean

Views differ on adequacy of Montreal protocol, proposed EPA rules

The Montreal protocol—the international agreement to curtail production of fully halogenated halocarbons—is considered in many quarters to be an unprecedented achievement. "The Montreal Protocol on Substances That Deplete the Ozone Layer will become a global turning point, a model for continued worldwide cooperation between government, industry, and public interest groups to safeguard our planet," G. Victor Buxton, chief of Environment Canada's chemical control division, told last month's conference on substitutes and alternatives.

Yet like the outcome of any negotiation, the protocol is a compromise among competing interests. U.S. industry, for example, while granting the need to halt the growth in output of fully halogenated materials, thinks cuts in chlorofluorocarbon (CFC) production are unnecessary. Nevertheless, industry representatives are urging the agreement be ratified.

"A freeze is sufficient to protect the environment and provide incentives to look for alternatives," says Richard Barnett, chairman of the Alli-

ance for Responsible CFC Policy, an association of CFC producers and users. "But since the international agreement calls for reduction we will capitulate, because the agreement is so important. Without it, our government is highly likely to do something more restrictive under pressure from environmentalists."

Indeed, Sen. Max S. Baucus (D-Mont.) has already asked that the first of the periodic scientific reassessments built into the agreement be held ahead of schedule. "The protocol is a significant step but doesn't go far enough," he says. "Recent evidence suggests that the problem is much more serious than we thought. When the protocol was drafted we didn't know the Antarctic ozone hole was caused by chlorine."

Baucus' views are echoed by David D. Doniger, senior attorney for the Natural Resources Defense Council. He points out that even with the 50% cut in CFC production called for in the protocol, the atmospheric concentrations of halocarbons will continue to grow because of their long lifetimes.

Consequently, he argues, the seasonal destruction of large amounts of ozone over Antarctica will continue to recur—and the phenomenon may spread elsewhere.

NRDC thinks the Environmental Protection Agency's proposals to enforce the Montreal protocol within the U.S. are inadequate. "The ozone layer will not be protected until the atmospheric stockpile of CFCs and halons is reduced and ultimately removed," Doniger says. "This requires a rapid, near-total phaseout of these chemicals, not merely a 10-year halfway measure."

Industry representatives, however, assert that the Montreal protocol and the proposed EPA rules are more than sufficient to protect the ozone layer. "Environmentalists argue that EPA hasn't used data from Antarctica and so should go further," says Joseph M. Steed, environmental manager for Du Pont's Freon products division. "We disagree. We think that EPA has been considering those data implicitly and that the regulations are adequate. Du Pont supports the ratification of the Montreal protocol."

ics. Similarly, halon 1211 (CF₂BrCl) is used in portable fire extinguishers where valuable equipment must be protected from damage by both fire and the extinguishing agents—airplane cockpits, for example.

Unlike CFCs, however, there are no known alternatives for the fire-fighting uses of halons, even in preliminary development. "There are no known substitutes and I'm not confident such substitutes will become available," says Billy Tullos, business manager for fluorocarbons for Great Lakes Chemical Corp. "The industry must respond by reducing unnecessary emissions."

Fortunately, reducing emissions may not prove too difficult. "Most halons are banked in tanks, awaiting future use," says Stephen Waters, president of Fireline Corp. "But what is emitted is for frivolous uses." For example, most emissions of halon 1301 are for discharge testing of total flooding systems.

The National Fire Protection Association (NFPA) has already backed

away from a standard it had proposed that would have mandated such discharge testing. Waters points out, however, that in reality many insurance companies and fire departments require full discharge testing even though NFPA doesn't. An alternative agent that could be used in discharge tests in place of halon 1301 is needed, he says.

The military, the major user of halon 1211 for fire-fighting training, is already taking steps to curb its uses of both halons. E. Thomas Morehouse of the Air Force engineering and services fire research laboratory describes several alternatives to actual fires that are being developed for training exercises. An interactive video like a computer game that simulates an actual fire has proved so popular that it is in use 24 hours a day, he says.

EPA has announced funding for outside researchers in response to the lack of viable alternatives for halons, says N. Dean Smith, a chemist with the agency's air and energy

engineering research laboratory in Research Triangle Park, N.C. The project is designed to look at completely novel compounds that have not been considered as alternatives to CFCs and halons, he says.

"The initial proposals will include synthesis of new compounds and determination of the relevant chemical properties," Smith says. "If any look favorable then we would probably follow up with atmospheric fate testing and preliminary acute toxicity tests. We'll keep industry informed and let them carry forward any promising candidates."

Industry already has an immense amount of work to do in the next decade on substitutes and alternatives for CFCs and halons. But now that restrictions on the output of those chemicals are inevitable, the race is under way. "Industry is running flat out to be the first with new compounds," says ICI's Harris. "In my 17 years with my company, I have never seen a project that received priority like this." □

The Great Lakes Cleanup Effort

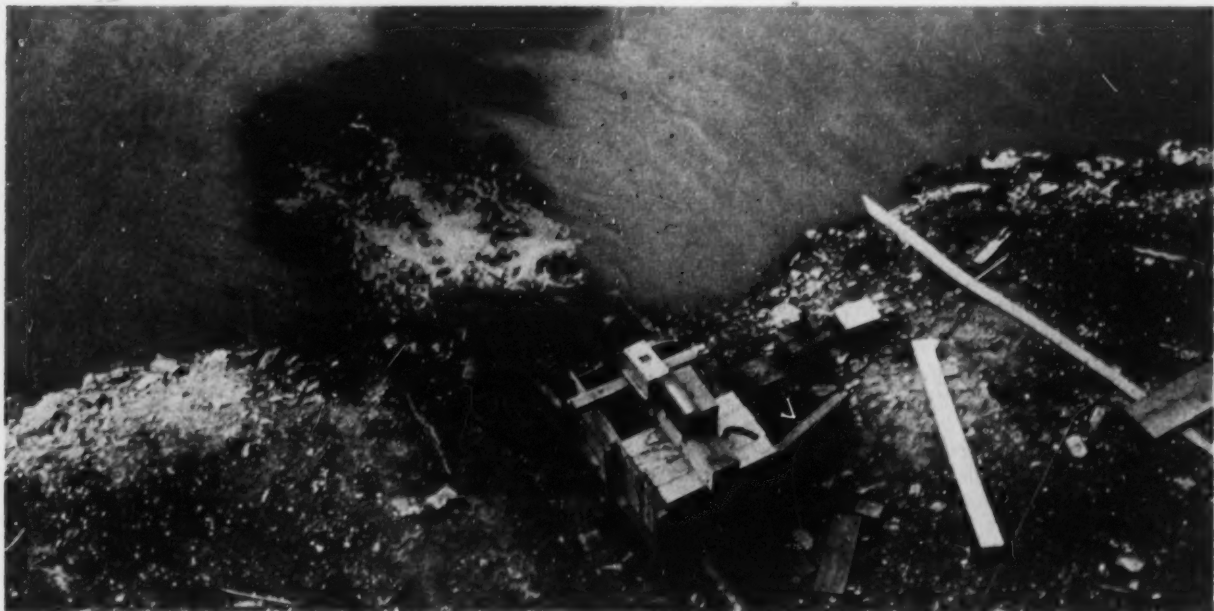
Much progress, but persistent contaminants remain a problem

Bette Hileman, C&EN Washington

The Great Lakes Basin is a complicated ecosystem without parallel anywhere in the world. Some have suggested that the ecosystem is in severe environmental difficulty, like a hospital patient staying alive only with a life support unit. A more accurate description might be that it is like a victim that was once about to lose one of its limbs, but now the limb has recovered to a large degree, although the whole body still suffers from a pervasive sickness.

The effort to clean up the Great Lakes began in 1972. In some ways, it has been successful. Other regions that intend to clean up large bodies of water, such as the Chesapeake Bay, are using the Great Lakes agreements as models of cooperation between different jurisdictions.

However, efforts to address the problem of persistent toxic substances in the Great Lakes are just beginning. During the past few years, scientists have learned that more than half the toxic substances deposited in some of the lakes are airborne. These are particularly



Michigan Department of Natural Resources photo

Outflows such as this into one of the Great Lakes are a major contributor to high pollution levels

hard to deal with. Also, more and more evidence has accumulated that toxic substances are causing fish tumors, birth defects in birds, and possible reductions in otter and mink populations. Their effects on human health are still uncertain and controversial.

One very positive recent step, meanwhile, is a new process created for developing remedial action plans for cleaning up so-called areas of concern—heavily polluted harbors, connecting channels, or river mouths near major municipal or industrial centers.

For nearly two centuries, the Great Lakes were thought to be almost immune from pollution because they are so large. They contain at least 95% of the surface fresh water in the U.S. and 20% of the world's fresh water. About two fifths of U.S. industry and about half of Canada's industry are located in the basin. Nearly 37 million people make their home there.

Owing to the lakes' immensity, it was believed for many years that almost any amount of waste could be dumped into them without affecting their integrity. And indeed, almost anything was put into them for nearly two centuries. They and the rivers leading into them served as large lagoons for sewer outfalls, depositories for industrial wastes, dumpsites for dredged polluted sediments, sinks for farmland and urban runoff.

But even the lakes have a dumping capacity that can be exceeded. The system is relatively closed. Less than 1% of the total volume of water in the system flows out the St. Lawrence River each year. Lakes Superior, Michigan, and Huron have especially long water retention times, which makes them particularly susceptible to pollutant buildup. On the average, water that enters Lake Superior takes 182 years to be flushed out again, for Lake Michigan it takes 106 years, and for Lake Huron 21 years. On the other hand, Lake Erie is flushed once every 2.7 years.

During the 1960s, observable pollution reached an extreme in the southerly third of the Great Lakes Basin. Henry A. Regier, zoology professor at the University of Toronto, called it "a vast ecological slum." With little government interference, industries were putting increasing amounts of wastes into the air, water, and land. Farmers were using large quantities of DDT and other persistent pesticides, and these were reaching the lakes through farmland runoff and atmospheric deposition. Sewers and sewage treatment plants were dumping rich loads of nutrients into the lakes and rivers leading into them. Wetlands near the lakes were being filled with waste soil and rubble.

In contrast, the middle third of the basin had been less damaged. Problems were apparent only in certain locales. In the northern third of the basin, the damage was even less obvious, except near mines and pulp mills.

By 1970, Lake Erie had lost nearly all its native fish. Algal mats covered the nearshore areas and the water had a noticeable odor. A *Life* magazine cover story in 1970 declared Lake Erie dead, and many believed that cleaning up the lake would be nearly impossible. Sport and commercial fishing for native fish had come to a virtual halt in both Lakes Erie and Ontario.

In 1972, the U.S. and Canadian governments responded to growing concern about deteriorating water quality in the Great Lakes by signing the first Great Lakes Water Quality Agreement. The agreement addressed primarily conventional pollutants—phosphorus, oil, and visible solid wastes. One of its goals was to reduce phosphorus to no more than 1 ppm in discharges from large municipal sewage treatment plants into Lakes Erie and Ontario, together with new limits on phosphorus from industrial plants. Implementation of the agreement was monitored by the International Joint Commission (IJC), an independent U.S.-Canadian agency created by the Boundary Waters Treaty of 1909 to advise and otherwise assist the governments under the treaty. Two bilateral groups were established to advise members of the IJC—the Water Quality Board and the Science Advisory Board.

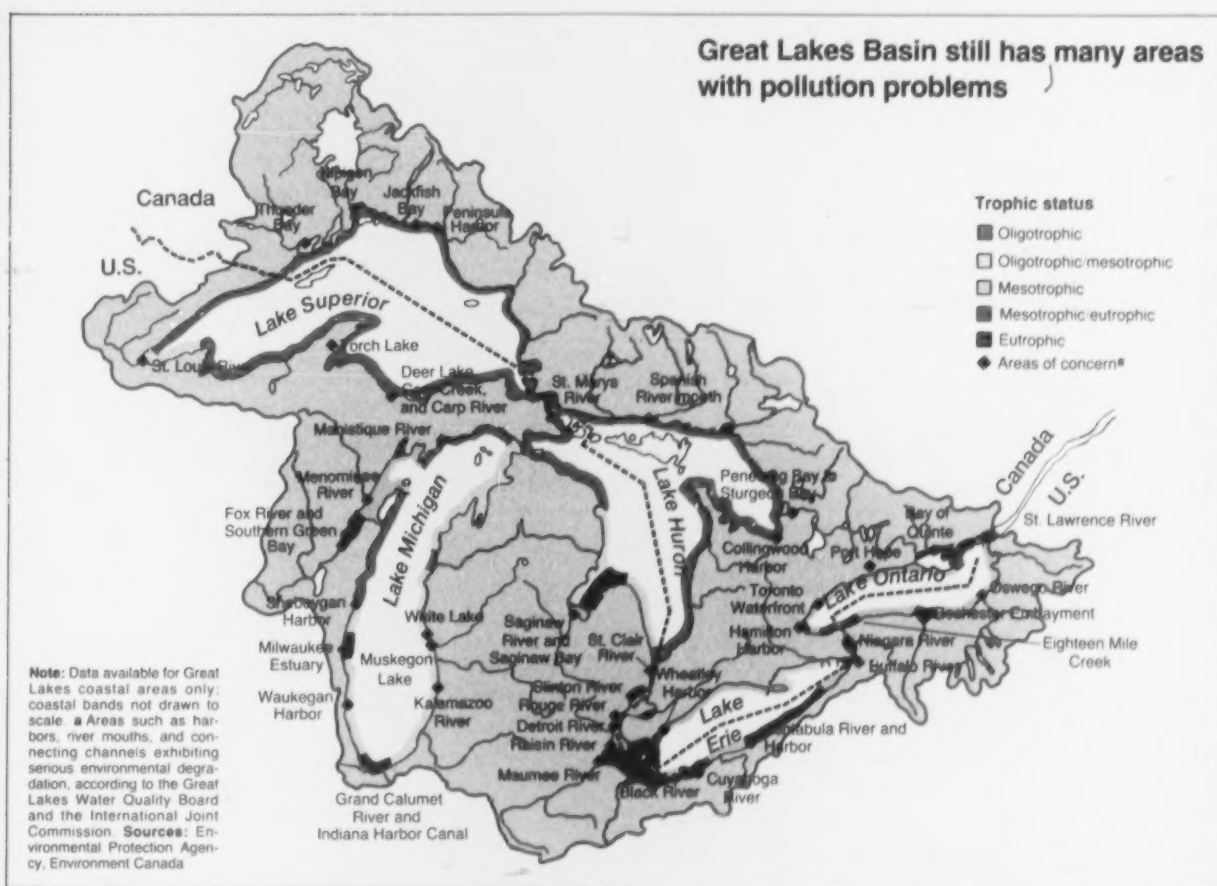
Visible evidence of progress was apparent during the first five years after the agreement was signed. By spending more than \$10 billion, governments reduced the total discharge of phosphates into Lake Erie and Lake Ontario drastically. Algal mats largely disappeared from Lake Erie, and the waters of Lake Erie and Lake Ontario looked and smelled better. Foul and unpleasant waterfronts that had been abandoned for all purposes except heavy industrial use were devel-

North shore of Lake Superior is still largely wild and uninhabited



Leanne Klyza/Lock photo

Great Lakes Basin still has many areas with pollution problems



oped as tourist areas. Sportfish began to return to Lake Erie, and the Cuyahoga River in Cleveland no longer caught fire occasionally as it had in the sixties.

However, during those five years it also became obvious that a number of problems had not been addressed by the original agreement. Fish in many areas of the lakes were heavily contaminated with polychlorinated biphenyls (PCBs), mirex (an insecticide and fire retardant), heavy metals, and other chemicals. Scientists gradually discovered that important sources of pollutants to the lakes had been overlooked the first time around. These included runoff from farmland and city streets; industrial discharges of pollutants other than the conventional waterborne pollutants (biochemical oxygen demand, suspended solids, and toxic metals); airborne toxic substances; contaminated groundwater; and polluted sediments. Researchers also concluded that phosphorus limits should be imposed for the upper lakes—Huron, Michigan, and Superior.

As a result, the U.S. and Canada signed a new water quality agreement in 1978. It established as a goal the virtual elimination of discharges of toxic chemicals. It also set more stringent overall reductions in phosphorus loadings for Lakes Erie and Ontario and for the first time set limits for the upper lakes. For the first time, the agreement also adopted an ecosystem ap-

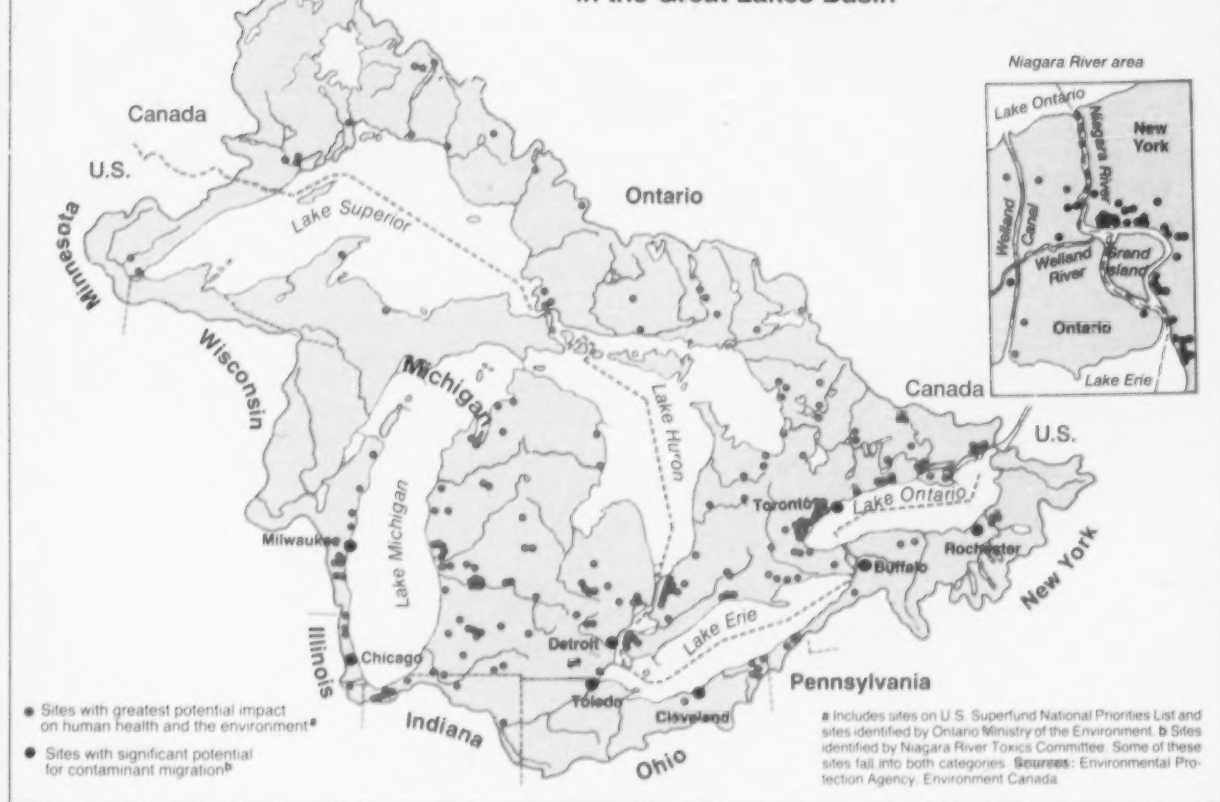
proach to cleaning up the basin "to restore and maintain the integrity of the waters of the Great Lakes basin ecosystem."

The 1978 agreement states that about 350 "hazardous polluting substances" should be banned from the lakes. Of these, the Water Quality Board of the IJC later identified 11 substances as critical pollutants. These are lead, mercury, hexachlorobenzene, PCBs, polynuclear aromatic hydrocarbons such as benzo[a]pyrene (BaP), 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF), and four organochlorine pesticides: mirex, DDT, dieldrin, and toxaphene.

Because progress in reducing the levels of several of these compounds in water and biota seemed to have come to a virtual standstill and because a joint National Research Council-Royal Society of Canada report pointed out many areas in which the 1978 agreement needed strengthening, both governments reviewed it in 1987. On Nov. 18, 1987, amendments to the agreement were signed by Environmental Protection Agency Administrator Lee Thomas and Canada's Environment Minister Thomas McMillan.

The new amendments reflect technical knowledge gained since 1978 and tighten up accountability and management. They set responsibilities and dates for completion of various milestones and reports, and

More than 100 major hazardous sites are located in the Great Lakes Basin



they stipulate a process for reviewing water quality goals and for preparing remedial action plans for the areas of concern. "As important as anything else, the amendments set new deadlines for reducing pollution," McMillan said during the signing ceremony.

In general, early progress in cleaning up the Great Lakes was relatively straightforward and simple, though expensive, and the results were obvious. Except for the heavily polluted areas of concern, future progress in cleaning up the lakes will be far more difficult to observe and probably also far more expensive. It will be seen in future fish advisories, as fish that are now considered too polluted to eat are given a clean bill of health, and in the receipts of commercial fishermen, as they are allowed to sell fish from more areas of the lakes.

As Thomas Brydges, scientist at Environment Canada (the Canadian equivalent of the U.S. EPA), explains, "Most of the problems that remain are subtle and in some areas it is hard to tell whether toxics really are causing damage. The problem of persistent toxic substances is the foremost problem confronting the Great Lakes. It will take more money and effort to control this problem than it has in the past."

The current overall condition of the lakes is fair to excellent in regard to phosphorus, deteriorating in regard to nitrogen, and mixed in regard to toxics. The

levels in water and biota of some toxics that have been restricted or banned, such as lead and DDT, have declined dramatically. Other persistent toxics have decreased only to a still unsatisfactory level. And some actually have increased.

Biological productivity is one way to measure the health of the lakes. This is the amount of living material supported within them, mostly in the form of algae. The least productive lakes are called oligotrophic, those with medium productivity mesotrophic, and those with the greatest productivity eutrophic. Several factors influence productivity—nutrients (nitrogen and phosphorus) received from the environment, temperature, light, and depth and volume of water.

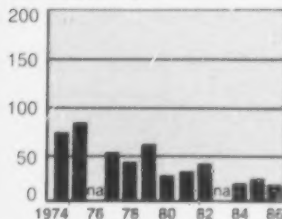
Though high productivity might sound like a positive attribute, it is unnatural for a large lake to be eutrophic or even mesotrophic. Before European settlement and industrialization, all the Great Lakes were oligotrophic except in marshes and shallow bays. Algal growth was low and the waters were clear.

The use of synthetic fertilizers and phosphate detergents adds enormously to the amounts of phosphorus and nitrogen available to the lakes. It stimulates the growth of green plants, including algae, just as adding fertilizer to a lawn stimulates its growth. When algae increase, bacteria that decompose the algae also

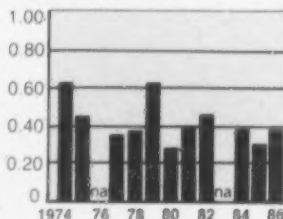
PCB, dieldrin levels in herring gull eggs from Great Lakes colonies are declining

Lake Superior

PCB, mg per kg

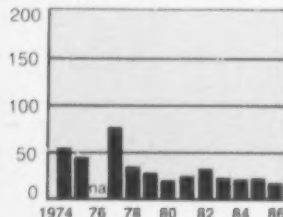


Dieldrin, mg per kg

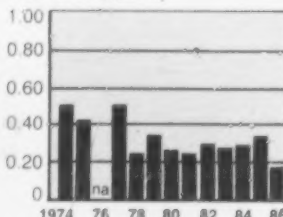


Lake Huron

PCB, mg per kg

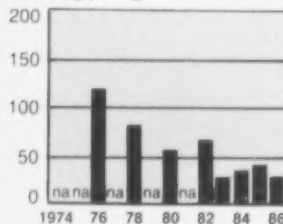


Dieldrin, mg per kg

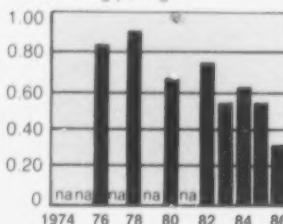


Lake Michigan

PCB, mg per kg

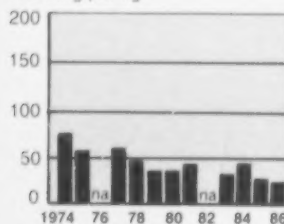


Dieldrin, mg per kg

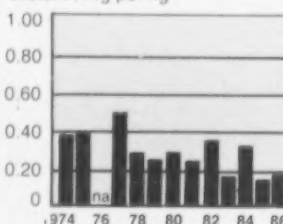


Lake Erie

PCB, mg per kg

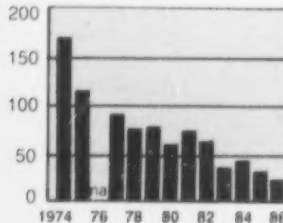


Dieldrin, mg per kg

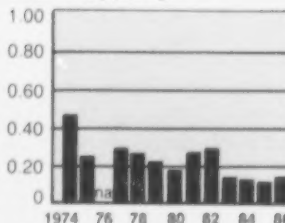


Lake Ontario

PCB, mg per kg



Dieldrin, mg per kg



na = not available Source: Great Lakes Water Quality Board

increase. The bacterial degradation of algae requires oxygen, and therefore depletes the water column of oxygen that otherwise would be available to fish. Marine animals that require little oxygen, such as sludge worms and carp, then proliferate. Demand for oxygen through decay of organic matter is called biochemical oxygen demand (BOD).

Today, the nearshore areas of all the Great Lakes except for Lake Superior suffer eutrophication problems. Because Erie is the shallowest and warmest of the lakes and has a large concentration of agriculture in its drainage basin and a highly urbanized shoreline, it suffered the greatest eutrophication in the sixties, before phosphate control began. Even now, "There is still high oxygen depletion in the bottom waters in the central basin of Lake Erie," says Valduis V. Adamkus, administrator of EPA Region V and U.S. cochairman of the Great Lakes Water Quality Board.

When the water quality agreement was signed in 1972, it was determined that reducing phosphorus inputs was the most direct way to solve the eutrophication problem. This is the success story of the Great Lakes cleanup. Phosphorus loadings to Lake Erie and Lake Ontario were cut about 80% by upgrading sewage treatment plants and decreasing the amount of phosphate allowed in detergents in the basin. However, Ohio and Pennsylvania still have not passed laws limiting the amount of phosphates used in detergents. At press time, the Ohio House had passed such a bill, but the Ohio Senate had not acted on it. "Ohio has not been very successful in many Great Lakes programs until just recently," says Robert Boggs, state senator from Ohio.

Efforts today to further reduce phosphorus loadings are focused on three areas: bringing more municipal wastewater treatment plants into compliance with the phosphorus limit of 1 mg per L of output; control of agricultural runoff through conservation tillage, fertilizer management, and animal waste management; and better monitoring of industrial point sources capable of releasing more than 1 metric ton of phosphorus per year.

Adamkus says EPA is generally "quite happy with compliance of U.S. municipal sewage treatment plants, but that financially strapped plants still do not comply." He adds that through very aggressive enforcement the U.S. "will try and meet the goal by July 1988."

Canada likewise reports progress. James N. Bishop, director of the water resources branch of the Ontario Ministry of the Environment, says that during the past two years there has been improvement in terms of overall loading, but that "the number of plants out of compliance is still high." These facilities, however, are either small or are only a little over the target. Ontario will begin to impose fines during the next two years on municipal and industrial plants that do not comply with emission goals, he says.

Agricultural initiatives in both countries are also being used to control phosphorus inputs. In the U.S., the adoption of conservation tillage (a method of planting crops without plowing the land) already has substantially reduced phosphorus runoff. In the fu-



EPA Administrator Lee Thomas, Canada's Environment Minister Thomas McMillan sign amendments to the 1978 Great Lakes Water Quality Agreement

ture, the U.S. plans to use existing programs to continue to encourage the adoption of conservation tillage. The Water Quality Board reports, however, that "the acceleration of U.S. phosphorus reduction programs called for in the [target load] plan is not taking place, particularly for programs supporting changes in tillage practices."

In contrast, the Canadian effort to reduce phosphorus inputs from agriculture will be carried out with a new program, called Soil & Water Environmental Enhancement Program (SWEET), to improve soil management and conservation practices on farms in the Lake Erie basin. Phosphorus from cropland sources will be reduced 200 metric tons (10%).

Fish manipulation strategies also can affect phosphorus levels in the lakes. When the population of large fish increases, more small forage fish are consumed. Because these forage fish eat zooplankton, the number of zooplankton that eat algae rises, so that more algae are consumed, clarifying the water. "It's not a simple situation," Regier explains. "There is a synergism in the recovery process, but it is not clear how these things interact. Bringing in big fish does help clarify the water, and keeping phosphate out also helps."

Nitrogen (measured as nitrate and nitrite) enrichment of the lakes is an issue that is not discussed very much, nor do its consequences seem to be very well understood. However, nitrogen levels have been rising in all five lakes. The annual rates of increase in open water range from 4.96 μg per L for Lake Superior to 10.03 μg per L for Lake Ontario. These increases appear to be largely caused by man.

Actions taken to reduce agricultural runoff of phosphorus will, of course, also decrease nitrogen inputs, as will efforts to cut back automobile emissions of nitrogen oxides. No focused program to reduce nitrogen inputs to the Great Lakes has been undertaken, however, and little research has been done on the

effects of nitrogen on aquatic life. According to EPA, only 8% of publicly owned treatment works in the basin provide high-level nitrogen control.

Timothy J. Kubiak, environmental contaminants specialist with the U.S. Fish and Wildlife Service, says nutrients in a lake interact with the toxic contaminants. For example, if the total amount of organic material, whether algae or particulate matter, is reduced, there is less of it to scavenge or adsorb toxic chemicals. Therefore more of the toxic chemicals may remain dissolved and the water quality may appear worse than otherwise.

Toxic contaminants a major issue

The issue of toxic contaminants in the Great Lakes in some ways seems hidden and subtle because generally the effects cannot be seen directly. Toxics do not cause obvious observable effects, such as algal mats and foul smelling turbid water. The levels of many of the contaminants in water are nondetectable, even with the best scientific instruments. Also, "At present, no concentrations of chemicals or heavy metals are found in the lakes at levels that are known to be acutely toxic to organisms during brief exposure," the EPA Great Lakes Office reports.

Between 1969 and 1972, legislation restricted or banned the use of dieldrin, heptachlor, DDT, PCBs, mercury, and mirex within the Great Lakes Basin. In general, concentrations of many of these contaminants declined significantly. The greatest decrease occurred between the mid-1970s and the early 1980s, with subsequent levels remaining fairly stable.

For the majority of organic chemicals among the critical pollutants, concentrations in most parts of the lakes are now so low that they meet the agreement standards. But in the areas of concern and in other nearshore areas at the mouths of tributaries, the levels of some of these organics are high.

PCB levels are an exception. They are higher than agreement levels of 1 ng per L in the western regions of Lakes Erie and Ontario as well as in Lake Michigan.

For metals on the list of critical pollutants, the situation is similar. In open lake waters, the levels are generally fairly low. But in many nearshore areas and in areas of concern, concentrations exceed the 1978 agreement objectives.

Though the water levels of some critical pollutants are high in some areas, the major concern about these pollutants is the effects they have on aquatic life and fish-eating birds as they bioaccumulate up the food chain. There is also concern about possible additive and synergistic actions of toxics on aquatic life, birds, and humans. The concentrations of some chemicals in the fat tissue of top predators, such as lake trout and salmon, can be a million times higher than the levels in the water.

Phytoplankton filter the water for nutrients and in the process scavenge persistent chemicals such as PCBs. Phytoplankton, in turn, are eaten by zooplankton and these by bottom-dwelling fish such as rainbow smelt. Predators such as lake trout and salmon at the top of the food chain then consume the bottom-dwelling

Special Report

fish. John J. Black, cancer research scientist at Roswell Park Memorial Institute, Buffalo, N.Y., calculates that to get as large a dose of PCBs as in 2 lb of lake trout contaminated with 2.5 ppm of PCBs (as many unrestricted sportsfish are), one would have to drink the Great Lakes water it lives in for 1000 years. Persistent toxics are biomagnified in fish-eating herring gulls and their eggs to an even greater degree than they are in fish.

High levels of contaminants in some species of fish have led to the issuance of fish consumption advisories. The larger, older fish in a species are most likely to be restricted. Nursing mothers, pregnant women, women who anticipate bearing children, and children under 15 are advised not to eat lake trout over a certain size from Lakes Michigan, Superior, Huron, and Ontario. In addition, men and women of all ages are advised against eating very large lake trout in all five lakes.

Contamination also has led to waterfowl advisories. The New York Department of Environmental Conservation has tested seven species of waterfowl for PCBs

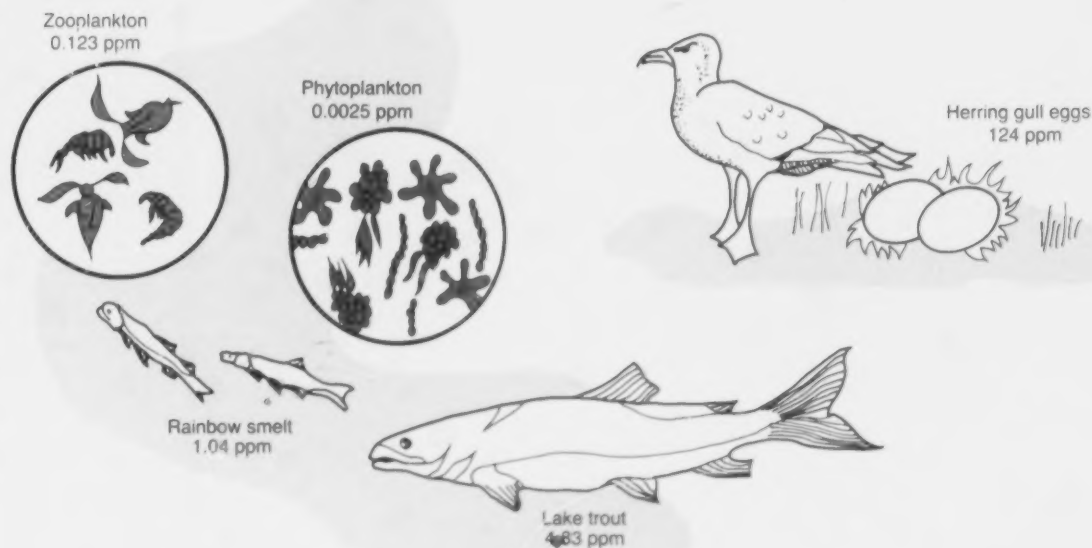
and organochlorine pesticides. Birds originating near Lake Ontario were found to have significantly higher concentrations of PCBs than birds in other flyways, except for the Hudson River, and were the only birds containing mirex. High levels of PCBs have caused waterfowl advisories to be issued for certain species of waterfowl in New York and Wisconsin.

Fish tumor outbreaks

Outbreaks of certain types of fish tumors, especially in heavily polluted areas such as harbors and the mouths of rivers, are believed to result from contaminants in the Great Lakes Basin. Fish tumors have been identified in 14 of the 42 areas of concern; for 24 of them no data exist on fish tumor incidences.

Even though the relationship between fish cancers and contaminants is not understood completely, recent research points more and more to pollutants as the only plausible cause of certain types, particularly those of the liver. John Harshbarger, director of the registry of tumors in lower animals at the National Museum of Natural History, says that all but one of

Toxic chemicals such as PCBs are biomagnified in the aquatic food chain



Phytoplankton collect the nutrients necessary for plant growth from a relatively large volume of water. In the process, they also collect persistent contaminants that may be in the water at concentrations so low they are undetectable even with very sensitive instruments. Small fish and zooplankton eat vast quantities of phytoplankton and further concentrate any chemicals accumulated by the phytoplankton. This biomagnification is repeated at every step of the food chain. Thus, as the diagram indicates, the concentration of polychlorinated biphenyls in rainbow smelt can approach

500 times that in the phytoplankton and the concentration in gull eggs can be 50,000 times higher.

Predators at the end of the food chain, such as lake trout, large salmon, and herring gulls, may accumulate levels of a toxic chemical high enough to cause serious deformities or death. Because they are at the end of the aquatic food chain, the eggs of fish-eating birds often have the highest levels of toxic chemicals. Consequently, dead or defective chicks are sometimes the first visible sign of contamination in the Great Lakes

the outbreaks of fish liver tumors he is aware of have occurred in areas with obvious sources of pollution.

"There are lots of other sites that are unpolluted where fish have cancer, but they are other types of cancer," he explains. He gives several examples of sites in the Great Lakes Basin where outbreaks of liver cancer have been found: the Niagara River, the mouth of the Cuyahoga River, the Buffalo River, and the Black River that empties into Lake Erie.

Because of the complexity of the natural environment, it may never be possible to prove absolutely a causal relationship between chemical contaminants in a waterway and liver cancer in fish. However, the "circumstantial evidence is so strong, it is almost impossible to deny," Harshbarger notes. He offers several reasons why liver tumors are associated with pollution:

- People had been looking for liver tumors in wild fish since the 19th century, but the first case was not found until 1964.
- In the lab, more than two dozen species of fish have been exposed to more than three dozen known mammalian chemical carcinogens and virtually every species developed liver tumors. Various other types of cancer also occurred fairly often, but not with the consistency of liver cancer.
- Roswell's Black applied extracts of sediments from two of the polluted areas where wild brown bullheads and catfish have cancer to the skin of healthy brown bullheads. He produced skin and liver tumors resembling those of the wild fish.
- Wild fish with liver cancer tend to be clustered where synthetic organic pollutants are concentrated.
- Scientists have failed to find any other cause, such as viruses or a genetic factor, for the liver cancers of fish in polluted areas.

Contaminants may be responsible for a number of other fish problems. Nearly 100% of coho salmon in Lake Erie have goiters. "They also lack secondary sex characteristics, have impaired lipid metabolism, are unusually small, and 75% of the embryos die," Harshbarger explains.

Birds and mammals

Toxic pollution also seems to be related to reproductive failure and birth defects among certain types of birds that feed on Great Lakes fish. Some of the affected species are herring gulls, double-crested cormorants, caspian terns, and Forster's terns.

By the late 1960s, cormorants on the lakes had been almost extinguished by a combination of human intervention and DDT contamination, which caused the eggs to fail because of thin shells. In an effort to save fish from cormorant predation, commercial fishermen often destroyed cormorant eggs and the Ministry of Natural Resources in Ontario used to spray a mixture of formaldehyde and soap on the eggs to kill the embryos while leaving the eggs intact. James P. Ludwig of Ecological Research Services in Bay City, Mich., estimates that the total Great Lakes cormorant population probably reached a low of 200 nesting pairs sometime between 1968 and 1973. By 1981, after DDT was

banned and the deliberate destruction of eggs stopped, the population had grown to about 3000 nesting pairs. Now it is estimated to be 10,000 pairs.

Unfortunately, at the same time the cormorant population increased, the percentage of cormorant chicks with a crossed-bill defect also may have risen. The first cormorants with crossed bills were seen in 1979, reports Kubiak of the U.S. Fish & Wildlife Service. Since then, he and other investigators found more than 60 birds with crossed bills mostly where Green Bay and Lake Michigan meet; none have been found in sites on Lake Superior, where the water quality is much better. Chicks with crossed bills generally live no more than a few weeks because their bills are useless for catching fish.

Ludwig and his coworkers have studied cormorant and caspian tern eggs from 12 colonies on the shores of Michigan. The percentages of defective embryos correlate well with the degree of contamination of the nesting sites. For example, cormorant and tern eggs from nests at a Saginaw Bay facility containing contaminated sediments had very high rates of defective embryos. None of the birds from these eggs fledged. "The wide distribution of defective tern and cormorant embryos suggests that all Michigan waters of Lake Huron and Lake Michigan are still significantly contaminated," Ludwig reports.

David J. Hoffman of the U.S. Fish & Wildlife Service and his coworkers, including Kubiak, also have studied reproductive success in Forster's terns at a colony on Green Bay. The hatching success of the Green Bay eggs was 52% of that at a control lake where the water quality is considerably higher. A new paper on this research proposes that certain dioxinlike PCB congeners may be causing the reproductive problem.

There is evidence, too, that contaminants in Great Lakes fish also may be affecting mink and river otters, both of which eat fish. The state departments of natural resources in Wisconsin and Michigan have found

Timothy J. Kubiak photo



Number of cormorant hatchlings with crossed bill defect seems to have increased in the past few years

that fewer otters are trapped near Lake Michigan than near Lake Huron.

Robert Foley, a biologist with the New York Department of Environmental Conservation, has found that the levels of organochlorine compounds in the organs of mink and river otter are highest in animals that live in areas close to Lake Ontario and in the Hudson River valley. The levels of PCBs he measured in some wild mink are as high or higher than levels that cause reproductive problems in controlled studies conducted on mink farms.

Clearly, more studies of birds and mammals in the Great Lakes Basin need to be done to better understand the causes of defective embryos and reproductive failures and to learn more about the extent of contamination problems.

Human health effects

Like everyone who lives in an industrial nation, people who inhabit the Great Lakes Basin are exposed to a large number of chemicals through a variety of pathways. Some observers believe, however, that exposure is higher than average for inhabitants of the basin. The joint NRC-Royal Society of Canada review of the Great Lakes agreement states: "The committee finds substantial evidence from the results of studies done by both the U.S. and Canada that the human population living in the Great Lakes Basin is exposed to, and accumulates, appreciably more toxic chemical burden than other human populations in similarly large regions of North America for which data are available."

Many scientists believe that the greatest exposure to toxics in the Great Lakes Basin probably comes from fish. Commercial fishermen and their families, sportfishermen and their families, and native North Americans who traditionally use fish as a large part of their diet continue to eat quantities of fish that far exceed the guidelines established by the U.S. and Canada. Even people who strictly adhere to the guidelines may be subject to a greater risk from fish than from other risky foods or other environmental exposures. For example, EPA estimates that the lifetime risk from eating one-fourth pound of mixed Lake Michigan fish per week is more than two orders of magnitude higher than that from eating 2 oz of peanut butter per week (usually contaminated with the natural mold aflatoxin) or of eating one-fourth pound of charcoal-broiled steak. Yet, a person who consumes that much fish is not exceeding the guidelines.

Harold E. B. Humphrey, an environmental epidemiologist with the Michigan Department of Public Health, has found that blood serum levels of PCBs and DDT are significantly higher in people who eat Great Lakes fish compared with those who do not. He also found a positive correlation between the length of time fish were eaten and blood levels of PCBs and DDT.

In addition, there is some evidence that other foods produced in the basin are more heavily contaminated with PCBs than those produced outside it. In 1976, Peter W. Saschenbrecker, analytical chemist at Agri-

culture Canada, found that PCB levels in Canadian beef are much higher in Ontario and Quebec (that is, the Great Lakes Basin and its outlet the St. Lawrence) than in the Atlantic or western provinces.

Breast milk, too, has a higher PCB level in Ontario (21 ppb) than elsewhere in Canada. In 1984, anthropologist B. Jill Smith found PCB levels of 45 ppb in breast milk of fish-eating women in Sheboygan, Wis., compared with 38.5 ppb in the milk of nonfish-eating women. An infant weighing 4 kg who drinks 600 mL a day of milk contaminated with 45 ppb of PCBs consumes 6.75 μ g per kg of body weight per day of PCBs, more than six times the maximum daily PCB safe dose set by the U.S. Food & Drug Administration. Studies by Joseph L. Jacobson of Wayne State University and his coworkers and Greta G. Fein of the University of Maryland and her associates have found that smaller birth sizes, lower gestational age, and neonatal behavioral deficits correlate with the mothers' consumption of contaminated fish. Though PCBs in fish seem a likely cause, other contaminants may be involved, the authors warn.

Controversial study

A recent report "Toxic Chemicals in the Great Lakes Basin Ecosystem: Some Observations," prepared by two employees of Environment Canada, has aroused a great deal of controversy. After more than a year's delay, Environment Canada paid for printing and circulating the report but did not make it an official publication.

The authors, Tom Muir, an economist, and Anne Sudar, a sociologist, summarized hundreds of scientific articles to correlate levels of contaminants in Great Lakes water, sediments, and biota with health effects on fish, birds, wild mammals, and humans.

In the report, the authors say that overall cancer death rates are higher in the Great Lakes Basin and the St. Lawrence River valley than in many other parts of the U.S. and Canada. They also find higher rates of heart disease and birth defects among Canadians in the Great Lakes Basin and in the St. Lawrence River valley than in most other regions of Canada.

Even though Muir and Sudar point out repeatedly that apparently similar trends do not prove a cause and effect relationship, it is the juxtaposition between the discussions of pollution levels and of human health effects that seems to have aroused the strongest objections from reviewers. They believe such juxtaposition leads the reader to conclude there is a cause and effect relationship.

Environment Canada says it is not publishing the report as an official document because "frequently in the text, two coincident sets of data are presented, one on the environmental occurrence of some toxic chemical (or mix of chemicals), the other on some sort of biological disorder. However, the authors draw no conclusion, knowing that they have not been able to do more than point out a coincidence. Without a more systematic approach, such observations are often misleading rather than helpful."

Canadian scientists contacted by C&EN, nearly all



C&EN staff photos

Kleveno (left): large reduction in chemicals throughout the lakes. Harshbarger (center): circumstantial evidence almost impossible to deny. Loucks: sources of pollutants to the Great Lakes fall into five major categories

of whom spoke off the record, are very strongly divided over the merits of the report. Those who favor it call it "very important, a revolutionary document akin to a 'Silent Spring' for people rather than birds." Those who oppose it call it "unscientific and misleading."

Whatever the merits of the report, it has one outcome that its critics consider positive. Because of the controversy over the Muir-Sudar report and the interest it aroused, a similar study will be undertaken by two Canadian agencies—Health & Welfare and Environment Canada—that in the past have been uncooperative and have not carried out joint projects. The Conservation Foundation, Washington, D.C., and the Institute for Research on Public Policy, Ottawa, will be covering the same issues in a book to be released in 1989. It will review the problems associated with making policy decisions under conditions of scientific uncertainty.

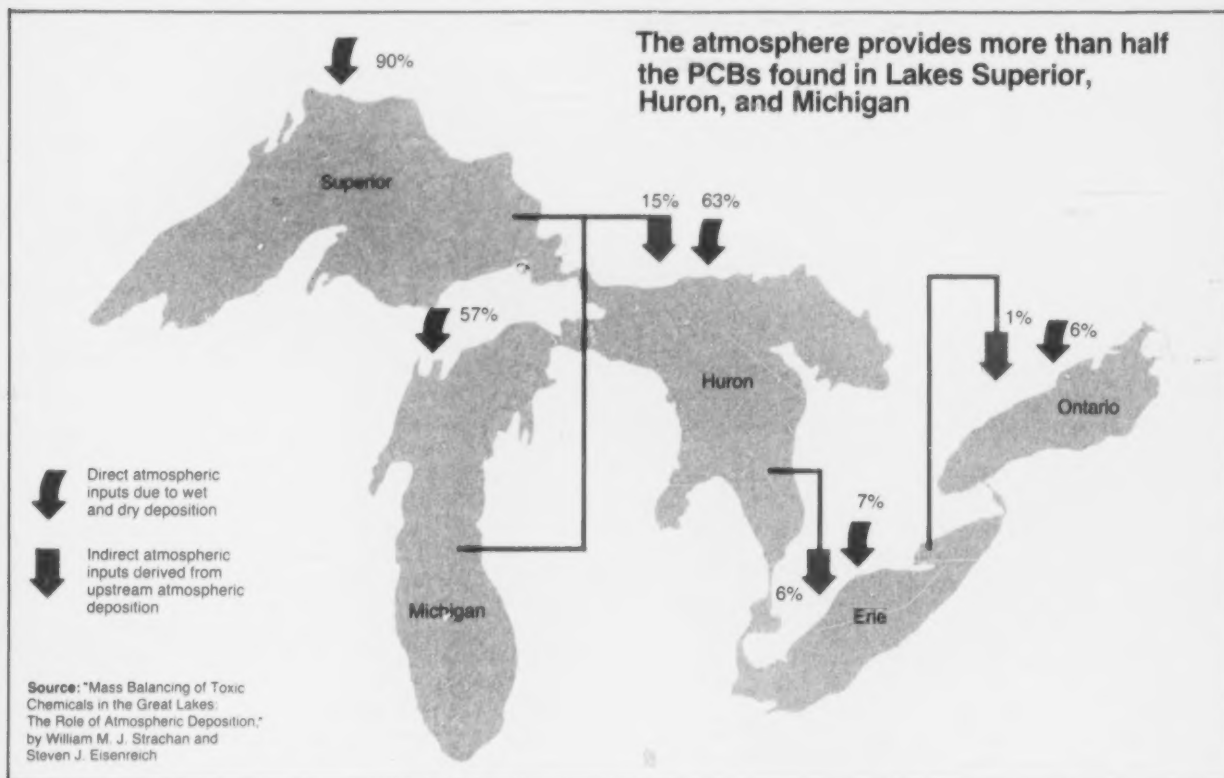
Sources of toxics

When the first water quality agreement was signed in 1972, it was generally thought that the two major sources of pollutants to the Great Lakes were municipal wastewater treatment plants and industrial discharges. If these two sources could be shut off, it was believed, most of the Great Lakes problems would be over. Gradually, however, more and more sources of pollutants came to be recognized as important. Now, the understanding is that over the whole basin, "the pollutants are divided about equally among five sources: the atmosphere, municipal and industrial point source discharges, farmland and municipal runoff, contaminated groundwater, and contaminated sediments," says Orie L. Loucks, director of the Holcomb Research Institute at Butler University in Indianapolis and coauthor of the joint academy review. Of these, the importance of airborne contaminants deposited in rain and snow, in airborne particulates, and as vapor has been recognized most recently.

Probably the most dramatic demonstration of airborne pollution came from the discovery in 1982 of toxaphene contamination of fish in a lake on Isle Royale in Lake Superior. Isle Royale is a national park with no human population and no sources of industrial contamination. The only plausible way toxaphene could have reached a lake on the island was through the atmosphere. Also, it came to be recognized that the levels of contaminants that were being measured in some of the lakes, particularly Lake Superior, could not be explained without atmospheric inputs. Lake Superior has a higher concentration of dieldrin (a banned pesticide) and only a slightly lower concentration of PCBs than three of the other lakes. Since Lake Superior is largely isolated from industrial and municipal sources, these substances must be transported by air throughout the basin.

Now it is believed that more than half the inputs of toxics to Lake Superior come from the atmosphere. For example, Steven J. Eisenreich, professor of environmental engineering sciences at the University of Minnesota, estimates that 90% of the PCBs in Lake Superior come from that source. Also, "For upper Lakes Michigan and Huron, we think the source of pollutants is primarily atmospheric," Eisenreich says. In general, the larger the surface area of the lake and the more remote it is from industrial and municipal sources, the larger is the percentage of atmospheric input.

The sources of airborne toxics to the lakes are numerous and some are believed to be very distant from the Great Lakes Basin. Also, some result from legal and generally accepted methods of waste disposal: the disposal of contaminated sewage sludge on land, the open lagoon treatment of toxic wastes (particularly by aeration), municipal waste incineration, sewage sludge incineration, and the stripping of groundwater to purify it. (Stripping is the forced removal of volatile contaminants from contaminated water to the atmosphere.)



EPA and Environment Canada are jointly developing a study for the IJC of the total emissions of airborne toxics over the entire U.S. and Canada. The investigation is restricted to substances on IJC's list of critical pollutants and three additional pollutants—cadmium, arsenic, and lindane. The study makes no effort to estimate how much of these emissions actually are deposited on the Great Lakes. However, because many of the sources are located in or near the Great Lakes Basin, a significant part of the total emissions must find its way into the lakes. Pollutants whose usage is now severely restricted in the U.S. and Canada may be finding their way into the lakes from sources as far away as Latin America.

The total airborne emissions of some of the pollutants investigated are extremely large, in the range of hundreds of metric tons per year. But it is impossible to quantify all of them.

Of those pollutants whose sources in the U.S. have been quantified, lead, cadmium, arsenic, mercury, and polycyclic aromatic hydrocarbons have the largest emissions. For all of these, municipal waste incineration is a source; for lead, cadmium, and mercury, it is a major source. For lead, cadmium, mercury, and arsenic, coal combustion also is a major source, and motor fuel combustion produces large amounts of lead and cadmium. Because the number of municipal incinerators in the U.S. is expected to grow from about 100 to about 300 in the next few years, incinerators probably will become even more important sources of airborne toxics in the future.

Even though lead emissions have declined sharply over the past several years and are expected to decline still further, motor vehicles still emit 15,400 metric tons each year. Municipal waste incineration is the second largest source, at 2800 metric tons.

Annual total emissions of arsenic are also large—in the range of 3300 metric tons. The use of arsenical pesticides is the major source, with coal combustion a close second.

Mercury is an unusual pollutant in that the natural sources are as large or even larger than the anthropogenic. The National Academy of Sciences estimates that natural sources emit 1000 metric tons annually, whereas man-made sources produce 650 metric tons. The largest single man-made source is coal combustion followed by municipal waste incineration. One problem with incinerators is that as the operating temperature is increased to produce more complete combustion of organic pollutants, more mercury is volatilized into flue gases.

Polynuclear aromatic hydrocarbons, which are measured as BaP, are perhaps the most difficult critical pollutant to regulate because wood combustion in stoves and fireplaces is by far the greatest source. Agricultural burning and wildfires are secondary sources.

The emissions of those critical pollutants that are no longer being manufactured in the U.S., or were never produced there directly, are impossible to quantify and extremely difficult or impossible to regulate. But because many of these are very persistent and can still

be measured in the air in the Great Lakes Basin, it is clear they are circulating through the environment.

For example, PCBs have not been manufactured for more than a decade, so present environmental releases come from PCBs in current use and from disposal sites. Releases result from fires, spills, and other accidents, and evaporation from landfills, where 140,000 metric tons are estimated to have been disposed of. The total amount of PCBs still in service in transformers and capacitors is about 340,000 metric tons.

Toxaphene, DDT, dieldrin, lindane, and mirex also are not now being produced in the U.S., and toxaphene and DDT are no longer being used. However, some fraction of the 550,000 metric tons of DDT and 320,000 metric tons of toxaphene used in the past is probably still cycling through the environment. Also, a part of the 11,000 metric tons of DDT used in Latin America each year may undergo atmospheric transport and deposition to the Great Lakes Basin.

Thus, barring a drastic change in lifestyle and the economy, such as banning woodstoves and coal and oil combustion, some airborne critical pollutants will continue to reach the Great Lakes. However, the amounts of some of those that become airborne can be

minimized by use of catalytic converters on wood stoves, by better controls on municipal waste incinerators, by better control of flue gases from coal combustion, by the controlled incineration of all the PCBs now in use or storage, and by considering the consequences of evaporation when designing waste treatment systems. Pesticides such as DDT and dieldrin that are no longer produced in the U.S. but are used in Latin America are impossible to deal with except with an international accord.

Hazardous waste sites

Reducing toxics that enter the Great Lakes from hazardous waste sites is nearly as complicated, or perhaps more complicated, and difficult to handle as airborne toxics. Toxics enter the lakes from landfills via surface water runoff, groundwater leaching, and volatilization and redeposition. There are 132 Superfund waste sites on the National Priorities List on the U.S. side of the Great Lakes Basin, and at least 10 major abandoned hazardous waste sites on the Canadian side. Contaminated surface and groundwater flowing from many of these finds its way into the lakes. None of the Superfund sites have been cleaned up completely.

In a three-mile strip along the U.S. side of the Niagara River alone, there are 164 toxic waste disposal sites. Of these, the U.S. Geological Survey has identified at least 57 that have a major potential for contaminant migration. According to Lindsay A. Swain, regional groundwater specialist with the USGS, a major man-made tunnel called the Falls Street tunnel is serving as a conduit so that 6 million gal of contaminated groundwater leak each day into the Niagara River gorge. A compact called the Toxics Management Plan and an associated Memorandum of Understanding have now been formed among the U.S., Canada, Ontario, and New York to clean up the waste sites and control municipal and industrial discharges along the Niagara River.

Even when a decision is made to clean up a Superfund site, dealing with the contaminated material so that it will not cause future environmental problems is difficult. If the material is merely removed from one site and placed in a so-called secure landfill with a liner, the liner eventually will fail. However, the contents of a Superfund site may be too large to be incinerated or treated any other way at a reasonable cost.

Similarly, active hazardous waste landfills that comply with current U.S. laws may present problems to future generations. Some of them are sited along the Great Lakes and rivers leading into them. When the liners fail, they too may require very expensive cleanup.

Swain points out that a large fraction of the basin is covered with outwash sand and gravel deposits. "These are usually very permeable and allow rapid vertical and horizontal flow of water and, if present, transport of any contaminants," he reports. Therefore, leachate from waste sites placed on these deposits could leak rapidly into the lakes.

Industrial discharges in both the U.S. and Canada

Airborne emissions of some critical pollutants in the U.S. are extremely large

	Metric tons per year
Lead	21,305
Gasoline combustion	15,400
Municipal waste incineration	2,800
Industrial processes	2,300
Coal combustion	778
Other sources	27
Arsenic	3,332
Use of arsenical pesticides	1,500
Coal combustion	1,390
Primary copper smelters	312
Other sources	130
Mercury	1,668
Natural	1,019
Use of consumer goods	352
Coal combustion	132
Municipal waste incineration	68
Copper smelting	41
Sewage sludge incineration	36
Other sources	20
Polynuclear aromatic hydrocarbons	655
Wood combustion	560
Prescribed forest and agricultural burning	40
Wildfires	20
Gasoline combustion	13
Coal combustion	8
Other sources	14
Hexachlorobenzene	21-29
Pesticide use	17
Manufacture of chlorinated solvents	3-11
Other sources	1

Source: International Joint Commission

have been reduced considerably. Many industries in the Great Lakes Basin on both sides of the border, however, are still not in compliance with their permits. In 1986, about 7% of major U.S. industrial plants in the basin and 44% of Canada's were out of compliance with the regulations on discharges. Another problem is that the discharge permits are primarily for the conventional pollutants such as suspended solids and toxic metals. Many other pollutants are unregulated. For example, the effluents from some hazardous waste treatment facilities contain as many as 300 chemicals, of which only 62 are regulated by EPA.

Several recent initiatives will help improve the situation. Ontario is developing a program called Municipal/Industrial Strategy for Abatement (MISA), which will require that industries use best-available technology treatment before discharging waste. The U.S. is implementing a pretreatment program for control of discharges from small concerns to municipal sewage systems. This has been a major defect in both the U.S. and Canadian programs for controlling industrial discharges because many small operations have been discharging directly into municipal sewage treatment systems. For example, in Ontario about 11,800 plants discharge into municipal sewers; only 154 plants are regulated.

During the process of Great Lakes cleanup, the greatest progress has been made through the upgrading of municipal wastewater treatment plants. Many old systems, however, still have what is called combined sewer overflows, in which storm water passes through the same pipes as sewage. During heavy rains, the volume is too great to be handled by the sewage treatment plant and storm water and untreated sewage overflow into a river leading to one of the Great Lakes or into the lake itself. Combined sewer overflows are a source of all kinds of contamination, including pollutants from small industrial concerns that discharge in sewage systems. Combined sewer overflows are a problem in nearly all the urban areas of concern. Michigan alone has at least 191 combined sewer overflows. Rochester, N.Y., is now spending \$750 million to separate its storm water system from the main sewage system. Unfortunately, the cost of

separating storm water pipes from the sewage system is more than some communities are willing to spend.

Because many of the critical pollutants for the Great Lakes, such as pesticides and PCBs, reside in soil and are strongly attached to soil particles, erosion from agricultural and urban land is a major source of toxics, especially for Lake Erie, which is bordered by intensely farmed and industrialized areas. This was first recognized in 1978 in a report prepared by the International Reference Group on Great Lakes Pollution from Land Use, a committee created by IJC to investigate urban and rural runoff. The levels of pesticides in urban runoff can be even higher than those in agricultural runoff, because the amount of pesticides used per acre on home lawns and golf courses is often higher than it is on farms.

Actions now being taken to reduce nutrient loadings from farmland also will reduce the amounts of pesticides that enter the lakes attached to soil particles. In addition, the government of Ontario is encouraging the use of integrated pest management, which minimizes the use of pesticides on farmland and therefore the amount entering the lakes.

Areas of concern

Perhaps the most positive development for the Great Lakes Basin that has taken place recently regards the 42 areas of concern. Twenty-five of these are in the U.S., 12 are in Canada, and five are in international waters under joint jurisdiction. Most of them are major municipal and industrial centers on Great Lakes rivers, harbors, and connecting channels, and in all of them the water quality is particularly degraded. Nearly all of them used to be plagued with bacterial pollution and eutrophication, but these conditions have been largely taken care of. Now, the major problem in 41 of the areas is persistent toxic substances.

A new process has been initiated for planning and implementing cleanup of these areas. Its development began in 1985, when the U.S. states and Ontario decided to create remedial action plans to restore beneficial uses such as fishing and swimming in all areas of concern within their boundaries.

What is different about remedial action plans is the

Public health agencies have issued advisories for consumption of certain Great Lakes fish

	Restrict consumption*	Do not eat
Lake Michigan	Lake trout 20 to 23 inches, coho salmon over 26 inches, Chinook salmon 21 to 32 inches, and brown trout up to 23 inches	Lake trout over 23 inches, Chinook salmon over 32 inches, brown trout over 23 inches, carp, and catfish
Lake Superior	Lake trout up to 30 inches, Walleye up to 26 inches	Lake trout over 30 inches, Walleye over 26 inches
Lake Huron	Lake trout, rainbow trout, and brown trout	—
Lake Erie	Carp and catfish (New York State waters—eat no more than one meal per month)	Carp and catfish
Lake Ontario	White perch, coho salmon up to 21 inches, rainbow trout up to 18 inches (eat no more than one meal per month)	American eel, channel catfish, lake trout, Chinook salmon, coho salmon over 21 inches, rainbow trout over 25 inches, brown trout over 18 inches

* Nursing mothers, pregnant women, women who anticipate bearing children, and children age 15 and under should not eat the fish listed in any of these categories.

way in which they are developed. According to the Water Quality Board, "Previously, separate programs for regulation of municipal and industrial discharges, urban runoff, and agricultural runoff were implemented without considering overlapping responsibilities or whether the programs would be adequate to restore all beneficial uses."

In contrast, a wide range of government agencies, local citizens, local environmental groups, and representatives of industry contribute to the development of remedial action plans. The theory is that only by involving all affected groups (called stakeholders) in the planning process will a workable cleanup plan be devised and financed. So far, public meetings to formulate remedial action plans have taken place in 32 of the 42 areas of concern.

Originally, the jurisdictions underestimated the time that would be required to develop remedial action plans and intended to submit all of them by December 1986. Now, most of the plans are scheduled to be completed by January 1990.

Contaminated sediments are a problem in 41 of the 42 areas of concern. These are a source of toxic inputs to the biota of the lakes. Pollutants adsorbed on the sediments can become biologically active by a variety of processes. Organisms living in the sediments can absorb or ingest pollutants and solubilize them. Wave action, particularly during storms, and currents can disturb sediments, releasing some of the toxics. Also, disturbances from shipping and dredging can release pollutants tied up in sediments.

Sediments are one of the most difficult problems to deal with because their volume is so large and U.S. experience in dealing with them is very limited. There are several ways sediments can be treated. They can be placed in confined disposal facilities next to or in the lake (a diked containment area), placed in a confined area inland from the lake, reused on land for agriculture or for quarry and strip mine reclamation, isolated and treated in situ, decontaminated after dredging, or placed farther out in the lake in open water.

None of these methods has been used very much except for placing the sediments in confined disposal facilities and dumping them farther out in open lake water. The major problem with confined disposal facilities is that water can wash off the sediments during heavy storms, carrying contaminants with it and sometimes removing fine sediments if the facility is not designed properly. In some jurisdictions, dumping contaminated sediment farther out in the lake is no longer acceptable because it is believed that many of the contaminants eventually will be released to the aquatic biota. During the next few years, EPA will fund several demonstration projects to try to determine the best ways to treat contaminated sediments.

Conrad Kleveno, director of bilateral relations for EPA's office of international affairs, expects the remedial actions plans to be implemented for all the areas of concern over the next five years. Then, he expects to see a "major reduction in chemicals throughout the lakes."

Because there are no objective criteria for listing or

delisting an area of concern, it is difficult to tell how to designate certain areas. A jurisdiction, which can be a city, county, or state, nominates a restricted region as an area of concern, using the loss of beneficial uses as a criterion. IJC then designates the area as an area of concern. It has no power to place a region on the list without the consent of the jurisdiction, however. Some observers argue that many regions that have lost beneficial uses should be on the list, but have not chosen to be listed. Another problem is that the only criterion for taking a region off the list is the decision that beneficial uses have been restored. In other words, after cleanup procedures have been carried out, there is no measurable way to tell if the area is clean enough.

A long, difficult process

Though the Great Lakes cleanup effort has made substantial progress since it was first initiated in 1972, solving the problem of persistent toxic substances will probably take many years. The basin is affected by a wide variety of sources of contaminants from both inside and outside the basin and a wide variety of environmental laws and regulations in both Canada and the U.S. Therefore, the toxics problem likely will never be addressed except in a piecemeal, temporary fashion unless people outside the basin, as well as the population within it, take an active interest in protecting it.

Some have suggested that the only way to ensure the continued health of the lakes is to eliminate inputs of persistent toxic substances into the lakes almost entirely. They advocate a change in lifestyle—a new way of thinking beginning in the home on a personal level. They urge people to consider what effects the products they buy may have on the environment—in their manufacture, use, and in the disposal of unused portions.

Such an approach could help in the cleanup effort. However, it also could lead the public to concentrate on single chemicals that are well-known pollutants to the exclusion of other, lesser-known substances that may be causing more damage—such as polycyclic aromatic hydrocarbons from woodstoves or cadmium from coal burning. Because society cannot control all pollutant sources completely, rational choices will have to be made between them and about the degree of control that is most desirable. The Water Quality Board expects public anxiety toward the effect of persistent toxic pollution to continue to grow. "This effect could represent a kind of 'microchemophobia' with the result that rational decisions could be compromised and significant resources could be misdirected to the wrong problem," the board says. □

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